BOTTLENECK-BASED HEURISTIC FOR PERMUTATION FLOWSHOP SCHEDULING

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DEDICATION

To my beloved parents Isa Bin Awang and Siti Hawa Binti Ismail.

Thank You Mom, Dad and Family members

For taking care of me and always standing right behind of me,

Supporting me in whatever decisions I make,

May Allah S.W.T grant all of you a Jannah.

To all my friends

Thank you for everything we shared.

For the laugh, cry and every moments,

I am the luckiest person to have all of you during my up and down.

PTTA UTHM
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PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRACT

The newly heuristic is developed by introducing the bottleneck-based concept that was applied at the beginning of initial solution determination. The heuristic is known as Bottleneck-Based (BNB) heuristic. The previous study found that the scheduling activity become complex when dealing with large number of machine, m > 2, it is NP-hardness. Thus, the main objective of this study are to propose and develop a new heuristic for solving permutation flowshop scheduling by considering four-machines and *n*-jobs (*n* = 6, 10, 15, 20). Three phases were applied into this study in order to boost the makespan performance of the proposed heuristic. Two phases (bottleneck identification phase and initial sequence arrangement phase) were newly introduced and combined with the existing famous Nawaz, Enscore and Ham (NEH) insertion technique. There are four potential dominant machines (M1, M2, M3, M4) clustered as bottleneck machines. A total 1000 set random processing time for each job sizes was tested using Excel simple programming with built in Visual Basic for Application (VBA). The heuristic performance was evaluated based on the average makespan ratio, average percentage error, and percentage of solution performance obtained. This study considered the NEH heuristic as the best and appropriate tool for comparison purpose since NEH heuristic is the best performing heuristic in minimizing the makespan. The heuristic evaluation result showed that the BNB heuristic is performing better than the NEH at bottleneck machines M1, M3 and M4. While, heuristic verification result showed that the bottleneck algorithms performed the best in minimizing the makespan for set of problems with bottleneck machine M4. However, the overall result showed fluctuate values over the size of jobs. The result of this study shown that the developed BNB heuristic achieved good performance in solving small sized problems however further modification is needed for medium and large sized problems.

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

ABSTRAK

Heuristik baru ini dihasilkan dengan memperkenalkan kaedah asas kejejalan dimana ia diaplikasikan pada permulaan penentuan penyelesaian awalan. Heuristik ini dikenali sebagai heuristik Berasaskan Kejejalan (BNB). Objektif utama kajian ini dijalankan adalah untuk menghasilkan satu heuristik baru untuk menyelesaikan masalah aliran penjadualan bagi empat-mesin dan *n*-kerja (*n* = 6, 10, 15, 20). Tiga fasa diaplikasikan dalam kajian ini dalam usaha untuk meningkatkan prestasi masa kerja siap dalam heuristik yang dicadangkan. Dua fasa baru diperkenalkan menggabungkan satu fasa sedia ada iaitu teknik sisipan NEH yang terkenal. Terdapat empat mesin dominan yang berpotensi (M1, M2, M3, M4) yang telah dikelompokkan sebagai mesin kejejalan selepas fasa pengenalpastian kekejalan. Semua jumlah 1000 data pemprosesan masa untuk semua saiz kerja telah diuji menggunakan program ringkas Excel dengan aplikasi pengaturcaraan makro Visual Basic (VBA). Prestasi heuristik dinilai berdasarkan nisbah purata masa siap kerja dan peratusan prestasi penyelesaian. Kajian ini mempertimbangkan heuristik NEH sebagai pengukuran yang sesuai untuk tujuan perbandingan memandangkan heuristik NEH merupakan yang paling terbaik dalam mengurangkan masa siap kerja. Keputusan menunjukkan heuristik BNB berprestasi lebih baik daripada NEH di mesin kejejalan M1, M3 dan M4. Sementara, keputusan verifikasi heuristik menunjukkan algoritma BNB berprestasi baik dalam mengurangkan masa siap kerja untuk beberapa set masalah untuk mesin kejejalan M4. Walaubagaimanapun, keseluruhan keputusan menunjukkan nilai yang berubah-ubah bagi setiap saiz kerja. Keputusan kajian ini menunjukkan heuristik ini berprestasi sangat baik dalam menyelesaikan masalah bersaiz kecil tetapi masih memerlukan pengubahsuaian untuk menyelesaikan masalah bersaiz sederhana dan besar.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CONTENTS

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF TABLES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF FIGURES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF EQUATIONS

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF ABBREVIATIONS

NEH	-	Nawaz, Enscore and Ham
VBA	-	Visual Basic for Application
BNB	-	Bottleneck-Based
PFSP	-	Permutation Flowshop Scheduling Problem
NP	-	Non-Deterministically Polynomial
SA	-	Simulated Annealing
CPU	-	Computational Time
CDS	-	Campbell, Dudek and Smith
GA	-	Genetic Algorithm
WY	-	Woo and Yim
RZ	-	Rajendran and Ziegler
FL	-	Framinan and Leisten
GS	-	Gelders and Sambandam
MN	-	Miyazaki and Nishiyama
NEHKK1	-	Nawaz, Enscore and Ham, Kalcynzki and Komburowski 1
NEH-D	-	NEH based on Deviation
FSMP	-	Flowshop Multiple Processors
CDS1	-	Campbell, Dudek, and Smith 1
PAM	-	Hundal and Rajgopal modified Palmer
CDS2	-	Campbell, Dudek, and Smith 2
HO	-	Ho Heuristic
GLB	-	Global Lower Bound
DC	-	Daniels and Chambers
CR	-	Chakravartyh and Rajendran
DCH	-	Daniels and Chambers Heuristic
SAH	-	Simulated Annealing Heuristic
FSDS	-	Flowshop With Sequence-Dependent Setup Times
PA	-	Percentage Advantage
API	-	Average Percentage Improvement
WPT-MS	-	Weighted Processing Time and Minimum Slack Components

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

Greedy-ET	-	Greedy-Type Procedure for Earliness or Tardiness
EDD	-	Earliest Due Dates
NEHedd	-	Nawaz, Enscore and Ham Earliest Due Dates
SPT	-	Simple Priority Rule
M1	-	Machine Number 1
M2	-	Machine Number 2
M3	-	Machine Number 3
M4	-	Machine Number 4

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

LIST OF APPENDICES

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Scheduling is an act of planning and prioritizing activities with the time limit for the job completion in order to meet with certain requirement, constraints or to achieve the goal of objectives (Emmons and Vairaktarakis, 2012). Since the time always be the greatest constraint, therefore the scheduling becomes very important to organize the activities efficiently and optimally (Xhafa and Abaraham, 2008).

In worldwide industries, scheduling plays an important role in the production system since the resources are becoming more critical to be controlled. The resources are referred to the machine, manpower, material and many more (Chakraborty, 2009). The greatest outcome can be gained if the scheduling of the resources is successfully organized. It was a great advantage to the manufacturer in worldwide industries if the latest successful researches easy to understand and easily applied to the current manufacturing system (Mukhopadhyay, 2015). Hence, efficient scheduling system helps the manufacturer to increase the profit by cutting all the unnecessary cost associated with inefficient scheduling (Sule, 2008).

PTTA UTHM
PERPUSTAKAAN TUNKU TUN AMINAH

Scheduling model were categorised into many categories such as flowshop, job shop, open shop and dependent shop (Kalczynski and Komburowski, 2005). In flowshop scheduling, all the jobs are processed on multiple machines in an identical sequence with same or different processing time. This flowshop scheduling is to reduce or minimize the completion time for all the processed jobs defined as makespan. The processing order of the jobs on the machine is the same for each subsequent step of processing and this is categorised as permutation flowshop scheduling (Marichelvam, 2014).

The permutation flow shop scheduling is a well-known combinatorial optimization problem that arises in many manufacturing systems. Over the last few decades, permutation flowshop problems have widely been studied and solved as a static problem (Rahman *et. al*, 2015). The permutation flowshop scheduling problem became famous and interesting topic among the researchers when Nawaz, Enscore and Ham (NEH) introduced the NEH heuristic around three decade ago where the heuristic was declared as the highest performing method in minimizing the makespan and achieved the answer near to optimum solution (Framinan *et.al*, 2003). Many researchers have modified or used NEH heuristic as a basis to improve the scheduling solutions (Woo and Yim, 1998; Allahverdi and Aldowaisan, 2002; Kalczynski and Komburowski, 2005; Kalczynski and Kamburowski, 2007; Dong *et. al*, 2007; Saleh, 2014; Isa, 2015). The current available heuristic for permutation flowshop scheduling problem was classified as constructive or improvement methods (metaheuristic). A constructive heuristic builds a sequence of jobs so that once a decision was made, it cannot be reversed. Meanwhile, improvement heuristic starts with any sequence of jobs and then attempts to decrease the value of the objective by amending the sequence. Clearly, an improvement method can be applied to the sequence obtained from a constructive heuristic (Osman and Kelly, 1996). As a continuing effort from the literature, this research is intended to improve the NEH solution and to develop a new constructive heuristic by using bottleneck-based (BNB) approach.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.2 Problem statement

In the production scheduling system, researchers have found that the scheduling activities became more complex when dealing with more than two machines and it became a NP-hardness problem. Non-deterministic polynomial-time hard known as NP-hardness, in computational complexity theory is defined as a class of problems that are informally said "at least as hard as the hardest problems in NP" (Wegener, 2005). The researches then have focused on the development of implicit enumeration technique. However, it leads to emphasize the development of heuristic to find a near optimal solution for large size problems since implicit enumeration technique have a major constraint that there is the limitation on the problem sized that can be solved by that technique in a reasonable time (Allahverdi and Aldowaisan, 2002). It is the reason on why it is difficult to produce a new heuristic with answer near to optimum solution for a large number of machines and jobs in permutation flowshop scheduling. NEH algorithm appears to be the best heuristic in solving the makespan criterion problem, but it is not wise to just rely on NEH heuristic without further study since the improvement can still be made. Framinan et.al (2003) and Abedinnia *et. al* (2016) recommended further studies to be conducted to the NEH by choosing different sorting criterion beside using the ascending order of indicator values. Thus, this study is about to create a simple heuristic to boost the scheduling performance with the objective of makespan minimization since the previous finding shows that the modification is needed in order to strengthen the heuristic. The idea is by developing a new heuristic for permutation flowshop scheduling using bottleneck-based concept. The bottleneck phenomenon occurs frequently in many manufacturing systems (Chen and Chen, 2009). Identifying bottleneck resources and scheduling the jobs rationally helps in ensuring the feasibility and effectiveness of scheduling result and also help in reducing the difficulty in follow-up scheduling. Zhang and Wu (2012) shows that the local search effort for the bottleneck machines has generate higher quality of solution result and at reasonable short computational time. In this study, the bottleneck concept was applied first as initial solution step before the insertion phase where it was used as an indicator value in identifying the bottleneck machines. Besides that, this study also increases the understanding of bottleneck-based concept by developing computer program that can be used to

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

robustly test the performance of the algorithms using Visual Basic for Application (VBA) in Microsoft Excel. Since all the data was tabulated in Excel spreadsheet, this research is providing more visible analyses on the performance of the bottleneck-based heuristic in permutation flowshop scheduling.

1.3 Objectives of the study

The objectives for this study are:

1. To propose and develop a new heuristic using bottleneck-based (BNB) concept for permutation flowshop scheduling problem.
2. To analyse the performance of the BNB heuristic in flowshop scheduling environment.

1.4 Scope of the study

The scopes for this study are as follow:

1. Apply bottleneck-based concept for flowshop scheduling using Microsoft Excel.
2. Perform the bottleneck-based concept by using measurement of 4 machines and *n*-jobs (n = 6, 10, 15, 20) in flowshop environment.
3. Measure the makespan performance of the case study by using Excel simple programming in Visual Basic for Application (VBA).
4. The performances of BNB heuristic were compared with the optimum solution (n = 6) and NEH heuristic (n = 6, 10, 15, 20).

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

1.5 Significant of the study

Almost all the manufacturing industries used the scheduling planning in their production system daily process. Scheduling heuristic studies is important because:

i. It helps the industries to minimize the idle time.

   When the job sequence was organized properly, the completion time can be reduced as well as the idle time.

ii. It helps the industries cutting the cost of underutilize skill labour and expensive machines.

   A simple programming used in scheduling activities that was easy to conduct can help the industries reduces the operation cost since the programming is well known and low cost.

iii. It increases the profit gained by the industries.

   The industries can reduces the operation cost through good and systematic scheduling activities, thus increasing the profit gained.

iv. It increases the related literature or academic reports in the field of production scheduling.

   Since the scheduling plays an important role in production and manufacturing industries, the latest research helps in guiding the industries and manufacturer in applying efficient scheduling system.

1.6 Thesis layout

The further design of this thesis includes the review of scheduling system and the method used to develop a heuristic by previous researchers in Chapter 2. The methodology on the techniques and procedure used in this case study was highlighted in Chapter 3. The heuristic procedure was briefly discussed, and also the result and discussion of heuristic performance and heuristic verification was presented in Chapter 4. Finally, the research conclusion and recommendation for future works was discussed in Chapter 5.

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

In this section, a literature review regarding the heuristic algorithm and information related to this topic was collected and reported. All the knowledge gained from the literature contributes in better understanding of the heuristic and also the concept used in this research. In general, this review was divided into subtopics which are scheduling, permutation flowshop scheduling, heuristic approach, solving scheduling problem and lastly a summary of chapter.

2.2 Scheduling

Scheduling is a planning activity with required task and with the time constraints to be performed. It is a decision making process (Marichelvam, 2014). Scheduling is considered as important factor in many manufacturing and services industries (Sule, 2008). According to Mendes (2013), scheduling is one of the most critical issues in the planning and managing of manufacturing process where the difficulty in finding the optimal schedule depends on the shop environment, the process constraint and the performance indicator. Production scheduling problems are faced by thousands of companies worldwide that are engaged in the production of tangible goods. Efficient scheduling leads to increased efficiency, utilization and ultimately, profitability. It is

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

the reason that has attracted the attention of many practitioners and researchers from both fields of production management and combinatorial optimization in solving the production scheduling problems effectively and efficiently (Xhafa and Abraham, 2008). In the scheduling process, the type and the amount of each resource need to be known so that we can determine when the tasks can feasibly be accomplished. When the resources have been specified, we can effectively define the boundary of the scheduling problem (Kenneth and Dan, 2013). In production planning terminology, scheduling models are divided into some categories known as flowshop, job shop and open shop scheduling.

2.2.1 Flowshop scheduling

In flowshop scheduling, each job processed by a series of machine must have the same sequence even though the processing times may be different. Most authors added the requirement that a job never revisits any stage which can be numbered as 1, 2,…, *m*, and every job visits them in numerical order. In a pure flowshop each job has m tasks and visits all stages (Emmons and Vairaktarakis, 2012). Generally, jobs may have fewer than *m* tasks and may skip over some stations. Jobs may skip some machines in a skip-shop (Chakraborty, 2009). There is a certain cases in flowshop identified as re-entrant flowshop which a jobs may recycle and be reprocessed at the same station in multiple times (Ahmad, 2009). But as long as all the jobs followed the same path, the systems is still considered as flowshop.

According to Mukhopadhyay (2015), in a more complex compound flowshop, each machine may be replaced by a set of parallel machines which each job can choose one form the first cluster, one from the second and so on. In a finite queue flowshop there is limited storage in front of machines other than the first. An important special case is when no storage is allowed except at the first machine. For example, in the metal processing industries, that requirement is frequently encountered where the metal is rolled while it is hot. Delays between operations result in cooling, making the rolling operation prohibitively difficult (Thomas and David, 1993). The simple variation of flowshop called as “skip shops”, re-entrant flowshop", "compound flowshop", and "finite queue" flowshop. The illustration may be seen in Figure 2.1. The descriptions of flowshop variation are as follow:

1. Skip shops

   Jobs may skip some machines and treated as zero processing time.
2. Re-entrant flowshop

   Jobs may repeat the process on certain machine.
3. Compound flowshop

   A group machine may replace the machine in the series.
4. Finite queue flowshop

   There is limited storage in front of machines.

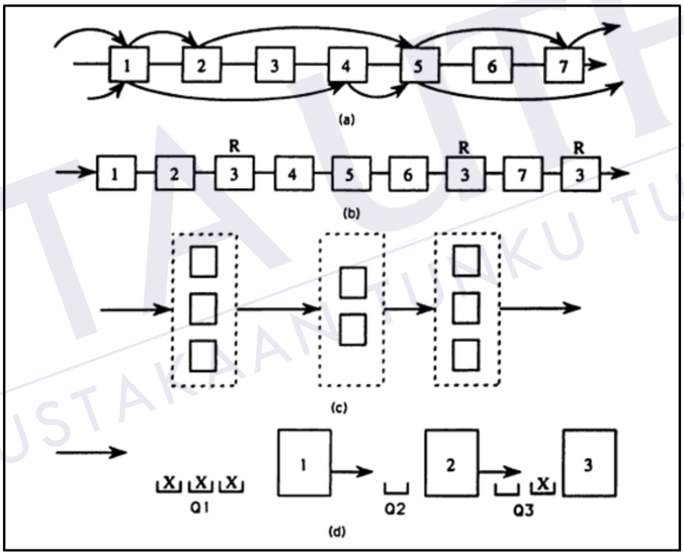

Figure 2.1: Flowshop scheduling illustrations (a) skip flowshop, (b) re-entrant flowshop, (c) compound flowshop, and (d) finite queue flowshop (Thomas and David, 1993)

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

2.2.2 Job shop scheduling

Job shop is the one that most commonly used in general production system. Job shop scheduling problems with setup times arise in many practical situations such as aerospace industries, fabrication industries, printing industries and semiconductor manufacturing industries (Sharma and Jain, 2015). There are several machines and jobs in the shop where some or all of machines were used in some specific sequence. Jobs are independent to each other. There is a restriction that a job cannot enter the machine more than once. Usually the main objective of job shop scheduling is to minimize the makespan or the tardiness penalty (Sule, 2008). Rui *et. al*,(2014) used the efficiency of ant colony algorithm for solving the job shop scheduling problem.

A job shop is also known as a multi-stage production system where each job needs to undergo several operations to become a finished product. In a job shop, only a single machine is capable of processing each operation (Chiang and Lin, 2013). This caused blockage in production when any machine breaks down. According to Li *et. al* (2014), job shop scheduling problem can be generalized into the flexible job shop scheduling problem (FJSP) where two sub-problems are solved. The first one is called a routing sub-problem that assigns each operation to a machine selected from any of a set of suitable machines. The second one is called a scheduling sub-problem consisting of sequencing all the assigned operations on all machines in order to yield a feasible schedule to minimize a predefined performance criterion.

2.2.3 Open shop scheduling

For open shop scheduling, there is no operationally dependent sequence that a job must follow. A job may enter the machines in any sequence that the job needs (Sule, 2008). The term ‘open shop’ is often simply taken to mean a shop that rather than directly to customer order, it produces to final inventory. Just like the flowshop and job shop, the open shop scheduling problem consists of a set of n jobs to be processed on a finite set of m machines. In general, each job must be processed on every machine and consist of a series of m_i operations which have to be scheduled in

PTTA UTHM PERPUSTAKAAN TUNKU TUN AMINAH

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